Mangrove ecosystem services assessment in Tanakeke Island, South Sulawesi

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Abstract. Mangrove ecosystems are among the most productive and valuable coastal habitats, providing crucial ecological and socio-economic services. However, intensive exploitation and land conversion have caused serious degradation, including in Indonesia, which holds about one-fifth of the world's mangrove forests. This study aims to assess the mangrove ecosystem services in Minasa Baji Village, Tanakeke Island, South Sulawesi, using the Common International Classification of Ecosystem Services (CICES) Version 5.2 framework. Data collection was carried out through household surveys involving 57 respondents, in-depth interviews, field observations, and secondary data sources. The results show that mangroves contribute significantly to provisioning services, including wood products for charcoal and fishing gear (126,000 kg/year), wild fish catches of 179,165 kg/year, and aquaculture production reaching 250,000 kg/year. In terms of regulating services, mangroves absorb 512.714 tons of CO_2eq, serve as nursery grounds supporting zooplankton abundance of 190 billion individuals, and act as nutrient exporters with nitrate concentrations higher inside mangroves (0.0102–0.0141 mg/L) than outside. Culturally, mangroves are viewed as inherited assets and marriage dowries, reflecting their deep symbolic value within the local Makassarese community. These findings emphasize the critical role of mangroves in maintaining ecological balance, local economies, and cultural identity. Strengthening conservation, rehabilitation, and community-based management is essential to ensure the sustainability of mangrove ecosystem services on Tanakeke Island.

1 Introduction

Mangroves are tropical coastal ecosystems that, along with coral reefs and seagrass beds, provide various ecosystem services and important ecological functions [1]. Ecosystem services refer to the benefits that humans enjoy from an ecosystem [2]. According to the Millennium Ecosystem Assessment (2005), ecosystem services are grouped into four categories, namely regulating, supporting, provisioning, and cultural services. As a provisioning service, mangroves function as a resource for capture fisheries (such as fish, crabs, shrimp, and squid), aquaculture, and a source of wood for charcoal production [3].

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Meanwhile, mangroves as a regulating service play a role in carbon storage, oxygen production, wave breaking, tsunami protection, and seawater intrusion prevention [4]. The supporting services of mangrove ecosystems include their function as nursery areas or feeding grounds for marine life [5]. On the other hand, the cultural services of mangroves generally take the form of non-material benefits that fulfill spiritual and religious needs, such as recreational sites.

Globally, mangrove ecosystems are recognized as one of the most productive and valuable coastal habitats, contributing significantly to climate regulation, shoreline protection, and the livelihoods of millions of people in tropical and subtropical regions. In Indonesia, which holds around one-fifth of the world's mangrove cover, pressures from coastal development, pond expansion, and overexploitation have led to widespread degradation. For example, in Tanakeke Island, South Sulawesi, mangrove cover decreased by about 28.3% (± 337.41 hectares) from 2000 to 2020 [3]. Despite the ecological richness including 11 species from 8 families and moderate diversity indices, health assessments indicate that these forests are in a low to moderate condition, particularly at the seedling level.

The ecological function of mangroves contributes greatly to their economic value. Mangroves are an important resource that supports the economy of the people of Tanakeke Island. The community converts mangroves into ponds and uses them as raw material for making charcoal, firewood, seaweed cultivation poles, and sero/bila fishing poles. According to Setiawan et al. [6], the residents of Tanakeke Island are highly dependent on the mangrove ecosystem to meet their economic needs. This high level of dependence has led to increasingly massive exploitation of mangroves.

The degradation of the mangrove ecosystem on Tanakeke Island has resulted in the loss of various ecosystem benefits, including ecological, physical, and economic aspects. Mangroves, in this context, play a key role in all three aspects. The decline in the quality of the mangrove ecosystem in the region has triggered various negative impacts, such as reduced fish diversity, decreased biological stability and productivity, increased abrasion in a number of villages, effects of extreme weather during the west monsoon (which causes tidal flooding in residential areas), and a decline in fish catches and aquaculture production [7]. According to local communities, such conditions were rare in the past when the mangrove ecosystem was still well preserved.

The evaluation of ecosystem services is a fundamental requirement in environmental management. In current practice, the CICES (Common International Classification of Ecosystem Services) approach has become a widely used standard. This classification system was first developed in 2009, then officially launched in 2013 through version V.4.3, and has continued to undergo refinements until reaching version V.5.2 in 2023. CICES is specifically designed to facilitate the process of measuring, quantifying, and assessing various ecosystem benefits. The calculation method in CICES is detailed with a tiered analysis approach [8]. Sustainable management of mangrove ecosystems in the future can be achieved, and management constraints can be overcome, by paying special attention to key issues encompassing ecological, economic, sociocultural, and institutional aspects. Understanding the valuation of the mangrove ecosystem services directly received by communities can provide a basis for community participation in protecting and preserving this source of income. This study has the specific objective of estimating the value of existing mangrove ecosystem services using CICES Version 5.2, with the study location in Minasa Baji Village, Tanakeke Island, South Sulawesi.

2 Methods

2.1 Time of research and background study of area

This research was conducted from August to November 2024 in Minasa Baji Village, Tanakeke Island, Takalar Regency, South Sulawesi Province. The observation location for data collection was determined using a field survey throughout the Minasa Baji Village area, which is used as a mangrove ecosystem service provider. The research location is shown in Figure 1.

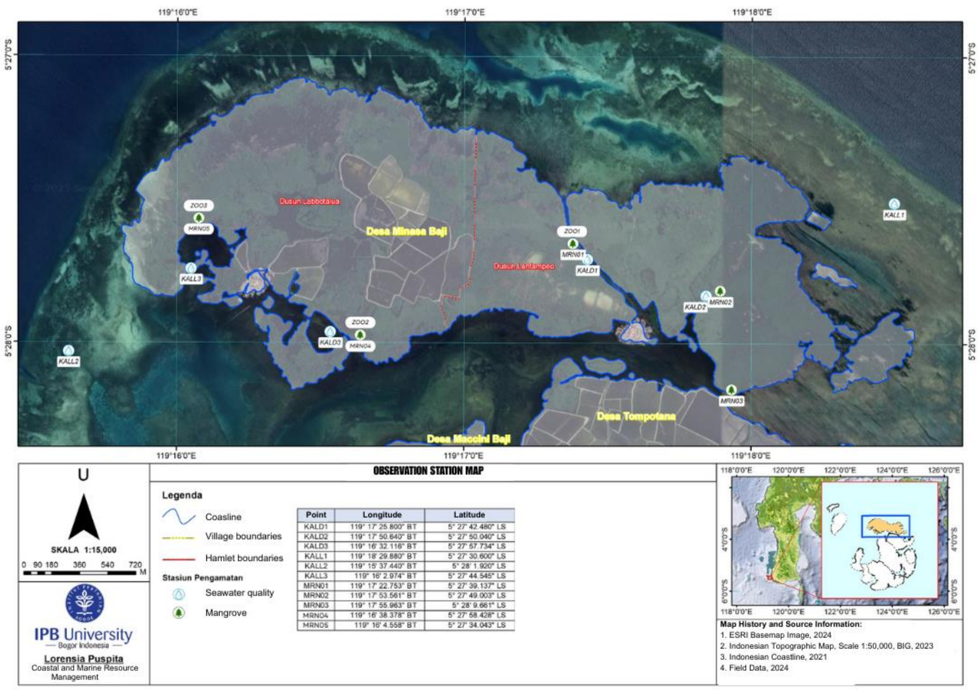

Fig. 1. Research location map. The shaded area denotes land, with the blue line indicating the coastline.

The selection of this location for data collection was based on the existence of the Bangko Tappampang area as a protected mangrove forest area in the region. In this area, there are village regulations governing the utilization and sanctions in mangrove forest management.

2.2 Processing procedure

This study collected data through two main types of sources, namely primary and secondary data. Primary data collection was carried out using three methods: (1) distribution of questionnaires to 57 respondents evenly distributed across two Sub-villages (28 respondents in Lantangpeo and 29 respondents in Labbotalua), (2) in-depth interviews, and (3) simultaneous direct observation in the field. For secondary data, the researcher used various sources including report documents, Excel spreadsheets, accredited scientific journals, peer-reviewed articles, official data from the Takalar Regency Central Statistics Agency, and various other supporting documents relevant to the research topic.

Data collection was conducted through questionnaires and in-depth interviews with community leaders, NGOs, fishermen, fish farmers, and charcoal makers to obtain information on their perceptions, activities, and involvement in the mangrove ecosystem. Data from the questionnaires were analyzed descriptively quantitatively using frequency and percentage tabulations to illustrate patterns of community perceptions and activities. Meanwhile, the results of in-depth interviews and field observations were analyzed qualitatively thematically, namely by identifying, grouping, and interpreting key themes related to the socio-economic interactions of the community and the condition of the mangrove ecosystem.

The questionnaire instrument in this study was developed by adapting the methodology introduced by Finisdore et al. [9]. The classification of mangrove ecosystem services was based on the Common Classification of Ecosystem Services (CICES), which was modified from the versions of Finisdore et al. [9] and Haines-Young [8]. Specifically, provisioning services such as livestock, aquaculture, and wild fish were measured using biomass units. For regulating services, calculations were made using methods of coastline change, zooplankton abundance in waters, and nutrient exports to the open sea. Meanwhile, cultural services were categorized into three main aspects: tourism, education, and research cultural services [8]. The collected data was tabulated, and the ecosystem services of each component were calculated as shown in the table below.

Table 1. Calculation of mangrove ecosystem services.

Ecosystem services	Division	5.2 Code	Description	Calculation	Unit
Mangrove provisioning services					
Wood	Biomass	1.1.5.3	Contribution of mangrove ecosystems to tree growth and wood biomass	Amount of wood used	Kg/ha/year
Wild fish and other natural aquatic biomass	Biomass	1.1.6.1	The contribution of mangrove ecosystems to the growth of fish resources and other aquatic biomass caught in the context of non-cultivated production by economic units for various uses, especially food production.	Catch x catch frequency	Kg/ha/year
Aquaculture provisioning services	Biomass	1.1.2.2	Contribution of mangrove ecosystems to aquaculture biomass harvest.	Harvest yield x harvest frequency x pond area	Kg/ha/year
Mangrove regulating services					
Carbon sequestratrion	Regulation of physical, chemical, biological conditions	2.3.6.1	Contribution of life system types to the number, concentration, or	Carbon value/ha x mangrove area	tonCO_2eq

Ecosystem services	Division	5.2 Code	Description	Calculation	Unit
			climate/atmospheric parameters		
Nursery ground	Regulation of physical, chemical, biological conditions	2.3.2.3	Provision of nursery grounds for fish and shrimp larvae	Abundance of fish and shrimp larvae	Ind larva/m3
Eksportir nutrient ke laut lepas	Regulation of physical, chemical, biological conditions	2.3.2.5	Nutrient provider for the open sea lepas	Increased NO3 concentration in the sea in front of mangroves	NO3 concentration in mangroves and in the sea in front of mangroves
Mangrove cultural services					
Spiritual, artistic and symbolic services	Spiritual, symbolic and other cultural interactions with natural environment	3.4.1.1	The contribution of mangrove ecosystems, particularly through the characteristics and quality of the ecosystem's biophysics, which are recognized by the community for their cultural, historical, aesthetic, sacred, or religious significance	Cultural diversity	Unit

3 Results and discussion

Minasa Baji Village is one of five villages on Tanakeke Island. Minasa Baji Village consists of four Sub-villages, namely Lantangpeo, Labbotalua, Bauluang, and Kampung Beru. The ecosystem shows fluctuations in mangrove area in Labbotalua and Lantangpeo Sub-villages during the period from 2015 to 2024. In Lantangpeo Sub-villages, there was a significant decrease in mangrove area from 96.11 ha in 2015 to 64.73 ha in 2020. This decline is thought to be due to anthropogenic pressures such as land conversion for seaweed cultivation or charcoal production. However, in 2024, the mangrove area increased sharply to 108.08 ha (Figure 2). This increase indicates successful rehabilitation or natural regeneration during that period.

Meanwhile, in Labbotalua Sub-villages, mangrove area experienced a downward trend from 114.58 ha in 2015 to 82.33 ha in 2020. Although there was a slight increase to 84.46 ha in 2024, over all it was still lower than the initial condition in 2015 (Figure 2). This indicates that pressure on the mangrove ecosystem in Labbotalua is relatively high and that it has not yet fully recovered, despite signs of recovery. The mangrove species *Rhizopora stylosa* is the dominant mangrove species in both Sub-villages.

The mangrove forest on Tanakeke Island, Takalar Regency, South Sulawesi, has provided benefits as a sustainable production forest area for the local community. The forest is managed independently by the residents. One of the mangrove areas, Bangko Tapampang, has been designated as a protected zone based on community agreement. To reduce damage caused by tree felling for charcoal production, the village government issued a Village Regulation requiring loggers to leave parent trees to ensure mangrove regeneration. The charcoal raw materials are obtained from mangrove forests, and are either owned by the community or purchased from other residents [10]

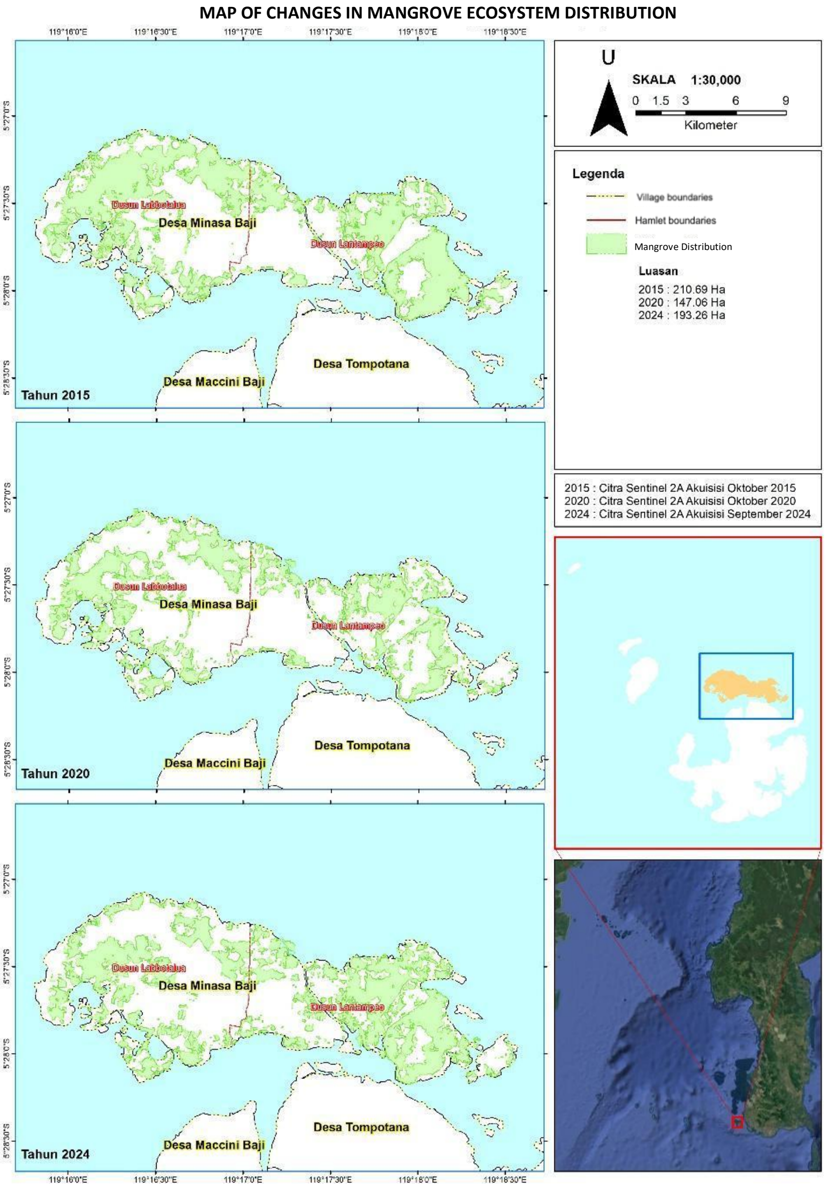

Fig. 2. Distribution of mangroves in Labbotalua and Lantangpeo Sub-Village in the years 2015, 2020 and 2024.

3.1 Provisioning services

3.1.1 Wood

In general, mangrove parts (wood and fruits) in Labbotalua and Lantangpeo Sub-villages are used as raw materials for charcoal, seaweed poles, sero/bila net fishing poles, and paropo fishing gear. Mangrove fruits are used for replanting. Based on interviews, the use of mangrove trunks reaches 126,000 kg/year for charcoal, 28,260 kg/year for seaweed poles, 59,500 kg/year for paropo, and 22,800 kg/year for sero/bila nets (Table 2).

Table 2. Quantity of mangrove ecosystem services in Labbotalua and Lantangpeo Sub-villages.

Utilization of mangrove wood	Area of land cleared (ha)	Weight of wood (kg/ha)	Production kg/ha/year	Yield
Charcoal	1.8	21,000	126,000	1,260 sacks
Seaweed poles	70.65	28,260	28,260	9,420 poles
Paropo	0.0153	59,500	59,500	19,833 poles
Sero/bila poles	4.56	22,800	22,800	7,600 poles

3.1.2 Wild fish and other natural aquatic biomass

The questionnaire results show that fishermen in Lantangpeo and Labbotalua Sub-villages use various fishing gears, including gill nets, sero/bila nets, paropo nets, and fish shooting. Based on these fishing gears, the target catches are fish, crabs, squid, and cuttlefish. The calculated biomass of catches (wild fish and other biota) reached 179,165 kg/year in Lantangpeo and Labbotalua Sub-villages. Details of the catches can be seen in Table 3.

Table 3. Quantity of wild fish and other aquatic biomass in Labbotalua and Lantangpeo Sub-villages.

Type of fishing gear	Area (fish/ha)	kg/ha	Frequency	Production (kg/year)
Sero/bila				
Siganus javus	4.2	1.4	312	433.3
Siganus sp.	4.2	1.4	312	433.3
Cuttlefish	8.3	2.1	312	650.0
Crab	12.5	3.1	312	975.0
Squid	8.3	2.1	312	650.0
Snapper	4.2	2.1	120	250.0
Grouper	4.2	2.1	60	125.0
Caranx sexfasciatus	4.2	2.1	18	37.5
Gill net				
Siganus sp.	571.4	190.5	12	2285.7
Snapper	571.4	285.7	12	3428.6
Grouper	571.4	285.7	12	3428.6
Caranx sexfasciatus	114.3	114.3	12	1371.4
Cuttlefish	2285.7	571.4	12	6857.1
Squid	2285.7	571.4	12	6857.1
***Paropo* (Traditional fishing gear)**				
Siganus sp.	22222.2	7407.4	3	22222.2
Snapper	33333.3	16666.7	3	50000.0
Grouper	33333.3	16666.7	3	50000.0
Siganus javus	33333.3	8333.3	3	25000.0
Dive fishing				

Type of fishing gear	Area (fish/ha)	kg/ha	Frequency	Production (kg/year)
Siganus sp.	200	66.7	12	800
Snapper	200	100	12	1200
Grouper	200	100	12	1200
Caranx sexfasciatus	60	30	12	360
Cuttlefish	100	25	12	300
Squid	100	25	12	300
Total				179,165

3.1.3 Aquaculture

Based on interviews with residents of Labbotalua and Lantangpeo Sub-villages, there were only about four fish farmers, all of whom were located in Labbotalua Sub-villages, with a total pond area of 75 hectares. The harvest per farmer varied between 25,000 and 200,000 fish per harvest, depending on the size of each farm. Harvesting is carried out twice a year. The aquaculture biomass (milkfish) produced in Labbotalua Sub-villages reached 250,000 kg/year, as detailed in Table 4.

Table 4. Aquaculture production in Labbotalua and Lantangpeo Sub-villages.

Pond area (ha)	Yield (fish)	Harvest frequency	Total yield (fish)	Total yield (kg/year)	Total (kg/year)
10 ha	50,000	2	100,000	33333.33	250,000
20 ha	100,000	2	200,000	66666.67	
40 ha	200,000	2	400,000	133333.33	
5 ha	25,000	2	50,000	16666.67	

3.2 Regulating services

3.2.1 Carbon stock estimates

The estimated average carbon stock value of mangroves in Labbotalua and Lantangpeo Sub-villages reached 722,882 tonsC/ha, equivalent to 2.652,98 ton$\boldsymbol{CO_2}$eq/ha. When multiplied by the total mangrove area of 193.26 ha, the total carbon sequestration potential reaches 512.714 tons of CO_2eq (Table 5). This value shows that the mangrove ecosystems in both Sub-villages play an important role as significant carbon sinks.

Table 5. Carbon sequestration in Labbotalua and Lantangpeo Sub-villages.

Carbon stock estimates (tonC/ha)	Estimated conversion of carbon to carbon dioxide (tonCO_2eq/ha)	Mangrove area (ha)	Total (tonCO_2eq)
722,882	2.652,98	193,26	512.714

3.2.2 Nursery ground

Mangroves contribute significantly to the surrounding ecosystem, as shown in the table of zooplankton numbers in the area. Based on field data, the species obtained were unidentified Gastropoda larvae, unidentified Annelida larvae, *Microsetella* sp, and *Balanus* sp. larvae, which are types of zooplankton that serve as food for fish or shrimp larvae. The average zooplankton abundance from the three observation stations ranged from 21,870 ind/L to 52,110 ind/L (Table 6).

Table 6. Zooplankton conditions in Labbotalua and Lantangpeo Sub-villages.

No	Organism	Sample Code								
		Number			Plankter/ml			Abundance/L		
	Species	1	2	3	1	2	3	1	2	3
1	Unidentified Gastropoda larvae	81	108	72	0.081	0.108	0.072	2,430	3,240	2,160
2	Unidentified Annelida larvae	27	0	36	0.027	0	0.036	810	0	1,080
3	*Microsetella* sp.	0	18	27	0	0.018	0.027	0	540	810
4	Larvae of *Balanus* sp.	36	54	54	0.036	0	0.054	1,080	0	1,620
					Average abundance (N)			21,870	44,280	52,110

The results of the calculations in Table 8 show the abundance of zooplankton in the waters of Lantangpeo and Labbotalua Sub-villages, with a total volume of 4,832 m³. Assuming a conversion rate of 1 m³ = 1,000 liters, the total volume of water reaches 4,831,500 liters. Based on the observation results, the average zooplankton abundance is 39,420 individuals per liter. With this value, the total number of zooplankton individuals in the waters is estimated to reach 190,457,730,000 individuals (Table 7). This figure illustrates the enormous and abundant potential of natural food resources in the study area.

Table 7. Zooplankton abundance in Labbotalua and Lantangpeo Sub-villages.

Water area (m3)	Water volume (liter)	Abundance ind/L	Total Ind
4,832	4,831,500	39,420	190,457,730,000

3.2.3 Exporter of nutrients to the open sea

The water quality around mangrove areas is an important indicator in assessing the health of coastal ecosystems. One key parameter to consider is the content of nitrate (NO_3), a compound that acts as an essential nutrient for the growth of phytoplankton and marine vegetation, but which in excessive concentrations can have negative impacts such as eutrophication [11]. Mangrove areas, with their unique physical and biological characteristics, often have complex nutrient dynamics, including nitrate cycles that are influenced by natural processes such as litter decomposition, microbial activity, and interactions with seawater and sediments [12].

Based on the data obtained, nitrate (NO_3) concentrations in the studied mangrove areas showed variations between locations within and outside mangroves. Nitrate values in mangroves ranged from 0.0102 to 0.0141 mg/L, while outside mangroves they ranged from 0.0056 to 0.0087 mg/L (Table 8). This indicates that nitrate concentrations tend to be higher in mangrove ecosystems than in surrounding waters.

High nitrate levels in mangroves can be attributed to the decomposition of organic material from mangrove leaf litter and microbial activity that recycles nutrients [12]. In addition, the complex root structure of mangroves plays a role in trapping sediment and organic matter, thereby increasing the accumulation of dissolved nutrients such as nitrate [13]. Conversely, lower nitrate levels outside mangroves may be due to factors such as dilution by seawater or high nitrate consumption by phytoplankton in open waters [14].

Table 8. Nitrate (NO_3) distribution within and outside mangrove areas

No	Sample Code	Unit	Location	Parameter

				Nitrate (NO_3)-mg/L
1	KALL1	mg/L	Outside the mangrove	0.0079
2	KALD1	mg/L	Inside the mangrove	0.0102
3	KALD2	mg/L	Inside the mangrove	0.0102
4	KALL2	mg/L	Outside the mangrove	0.0087
5	KALL3	mg/L	Outside the mangrove	0.0056
6	KALD3	mg/L	Inside the mangrove	0.0141

The nitrate (NO_3) concentration in the mangrove area was recorded at 0.0041 mg/L with a water volume of 48,315,000 liters. From these calculations, the nitrate content stored in the mangrove area's water system is approximately 198,092 mg (Table 9). This value indicates that although the nitrate concentration is relatively low, the total amount of nutrients in the area is quite large due to the large volume of water.

Table 9. Nutrient levels (NO3) inside and outside mangrove areas

Volume (m^3)	Water volume (Liter)	Nitrate (mg/L)	Total nitrate (mg)
48,315	48,315,000	0.0041	198,092

3.3 Cultural services

3.3.1 Spiritual, artistic, and symbolic services

The population of Tanakeke Island is dominated by indigenous Makassarese people who originated from mainland Sulawesi and have settled permanently on the island. For them, mangrove forests have the same value as land-based plantations and are considered hereditary assets. The majority of mangrove ownership is obtained through inheritance, while a small portion is acquired through purchase. In line with this, Setiawan [15] notes that the community uses mangroves as dowries for marriage and passes them on to the next generation. This view arises because the communities around Tanakeke Island regard the mangroves in their area as private property, so their management is similar to that of land-based plantations.

The total area of mangroves in the two Sub-villages (Labbotalua, Bangko Tapampang, and Lantangpeo) reaches 193.26 ha. The distribution of this area varies, with Labbotalua Sub-villages having the largest mangrove area of 84.46 ha, followed by Lantangpeo with 68.42 ha, and Bangko Tapampang with an area of 40.38 ha. Based on this, the area of mangrove utilization that can be used as cultural value (marriage dowry) is 152.88 hectares.

4 Conclusion

The study concludes that the mangrove ecosystem in Minasa Baji Village, Tanakeke Island, provides crucial ecosystem services that sustain both the environment and local livelihoods. Through the CICES v5.2 framework, the research identified significant contributions across provisioning, regulating, and cultural dimensions. Provisioning services include the production of mangrove wood (used for charcoal, fishing tools, and seaweed poles), wild fish catches totaling 179,165 kg/year, and aquaculture yields of 250,000 kg/year. Regulating services highlight the role of mangroves as major carbon sinks with 512.714 tons CO_2e absorbed, as nursery grounds supporting zooplankton abundance of 190 billion individuals, and as nutrient exporters enhancing marine productivity. Culturally, mangroves function as inherited assets and marriage dowries, reflecting their deep symbolic and social importance within the Makassarese community. Overall, these results emphasize that mangrove sustainability is crucial for maintaining ecological balance, economic stability, and socio-cultural continuity. Therefore, conservation, rehabilitation, and community-based management must be strengthened to ensure the long-term sustainability of mangrove ecosystem services in Tanakeke Island.

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